

Tri-service DoD Partnership Delivers Standard Product To Span Acquisition/Test Process

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The U.S. Air Force Electronic Warfare Evaluation Simulator (AFEWES) is a world class, secure, government-owned, contractor-operated, electronic warfare test facility located in Air Force Plant #4, Fort Worth, Texas. AFEWES is managed by the Electronic Warfare Group, Air Force Flight Test Center, Edwards Air Force Base, California. The AFEWES mission is to perform effectiveness testing of DoD and allied electronic countermeasure techniques to enhance aircraft survivability in combat. This paper will focus on four tri-service projects, led by AFEWES, which provide a common standard across test and evaluation resources; from digital models, through hardware-in-the-loop facilities to open air ranges. One effort is complete; the second is nearing completion; the third and forth are anticipated to begin in 2008. The four projects involve surface-to-air and air-to-air infrared seeking missiles, as well as surface-to-air radio frequency seeking missiles. The paper will discuss the process and tools used to gather and communicate requirements to the intelligence centers tasked to integrate portions of Threat Modeling and Analysis Program (TMAP) models for missile flyout models (FOMs) suitable for integration by Air Force, Army, and Navy (tri-service) T&E facilities. The paper also identifies the challenges AFEWES encountered and overcame to incorporate the flyout model (FOM) component of the TMAP threat models into real-time simulations. Successes include completed integration at tri-service facilities. The paper also highlights:

- the verification method being used that led to successfully integrating TMAP models at tri-service facilities
- the lessons learned during the execution of the first two efforts
- recommendations for other test capability providers

I. Introduction

Military testers must convince themselves, as well as the Department of Defense (DoD) decision authorities, that they have planned and performed evaluations using credible test tools to prove the military readiness of electronic countermeasures. To do so, test teams are looking for test capabilities that are both validated and show consistency from test to test. The need for this credible test capability is inherent in the documented needs of all DoD countermeasure testers since they require threat representative Surface-to-Air-Missile (SAM) and Air-to-Air Missile (AAM) flyout models (FOMs) to realistically evaluate Infrared (IR) and Radio Frequency (RF) countermeasures.⁴

II. The Problem

The problem of non-validated threat test capabilities has been a test shortfall since the beginning of the Test and Evaluation (T&E) of Electronic Warfare (EW) systems. Simulators built to replicate a threat to US weapon systems have given different results as a tester moves from digital model to Hardware-in-the-Loop (HITL) facility to the Open Air Range (OAR), or from Navy test capability to an Air Force test capability. Although there are many

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⁴ FY06 CTEIP Annual Write-up, IR FOM, 2 October 2006, Stone

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variables that go into a complete threat system simulator, the problem of Flyout Model FOM credibility and consistency has been at the forefront. Past efforts to address this problem have all fallen short of arriving at a common solution, usually due to modeling entire threat systems rather than focusing on standard test capability development to merge HITL assets with digital FOMs. In 2003, the lack of commonality between services, and even within the same service's test ranges/facilities, still plagued the test community. Although there were several T&E agencies that understood the problem and need for a solution, there was no single government office that was manned or funded to solve the problem.

III. An Overview of One Solution

A solution would be for a DoD organization to lead a formalized effort that would both encourage the use of service defined FOMs at the T&E facilities and fund a standard, intelligence developed FOM for each of the threats in the test inventory.

The answer came from the grass roots of the test community. In 2003, the 412th Electronic Warfare Directorate (now the 412th Electronic Warfare Group) chose the Air Force Electronic Warfare Evaluation Simulator (AFEWES) Program Manager to lead his proposed tri-service effort to develop T&E versions of two tri-service IR FOMs.⁵ The project included the cooperation and assistance of the Defense Intelligence Agency/Missile and Space Intelligence Center (DIA/MSIC), the Navy Threat Signal Processor-in-the-Loop (T-SPIL), and the Army Threat Systems Management Office (TSMO). This coordinated proposal was presented to the Threat System Working Group (TSWG) (then called the Threat System Investment Working Group (TSIWG)). The proposal was endorsed by TSWG, the Test and Evaluation Threat Resource Activity (TETRA) and the Director, Operational Test and Evaluation (DOT&E). It was then funded by the Office of the Secretary of Defense (OSD) Test Resource Management Center (TRMC) Central Test and Evaluation Investment Program (CTEIP). This project was selected because of two key components that were unique and promised success. The first component was that the FOMs would not be developed by a test facility (or multiple test facilities), but rather, would be developed by the appropriate intelligence agency as part of their support to their analysts, the warfighter, the T&E community, and multiple other customers. The model is the intelligence community's assessment of a specific threat's capability. The second component was that each test facility or range would use the core model as delivered and only make changes in the integration wrapper of the model.

The technical approach that was used took advantage of the revolutionary change in the intelligence agency's method to digitally represent threat systems, such as SAMs, AAMs, etc. The United States' intelligence centers began using the Commercial-Off-the-Shelf (COTS) The MathWorks™, Inc. products to build dynamic definitions (i.e. digital models) of their threat assessments. These models, called Threat Modeling and Analysis Program (TMAP) models, were primarily for the intelligence analysts' use. The models also served as a definition of the threat system to T&E simulator developers. The approach that the AFEWES-led TSWG project took was to have DIA/MSIC add access/control points to the base TMAP model without modifying the performance of the DIA developed model. The T&E test capability developers then integrated the TMAP model directly into their simulations without any changes to the model's functionality. These TMAP models used Real-time Workshop (another The MathWorks™, Inc. product) to provide a real-time model in the C/C++ language to communicate with existing HITL architectures. To ensure the test facility developers did not alter the core TMAP model performance, checkout data was taken to document simulator operation; HITL [as-installed] performance data was compared to the TMAP model performance by DIA/MSIC. Following a determination of successful performance, DIA/MSIC provided letters of validation to each test facility.

The success of the FY05/06 IR FOM project was instrumental in the TETRA decision to fund an FY06/07 project to start addressing the RF threat simulator FOM problem. This project was also led by AFEWES and built upon the methodology and lessons learned from the IR FOM project. The initial RF FOM effort would provide two FOMs for integration into the AFEWES, Navy Missile on the Mountain (MoM), and Army TSMO (TSMO is only fielding one of the threats). This project is ongoing and will conclude in the spring of 2008. Building on the success of the previous IR and RF FOM projects, TETRA encouraged the continuance of this successful partnering and took a leadership role in funding all infrared flyout models in FY08-11 and sponsored an effort to have CTEIP fund the remaining RF flyout models beginning in FY08. As of this writing, these two new FOM projects are being kicked off for FY08.

⁵ Concept paper, IR SAM MATLAB/Simulink® Conversion Flyout Model (IR MATLAB FOM), 14 March 2003, Stone

The first of these two projects is the IR Threat Missile Model Integration project that will integrate the FOM component of ten DIA/MSIC IR SAM models into two test facilities (four into AFEWES and eight into the Guided Weapons Evaluation Facility (GWEF)). In addition, this project will integrate two National Air and Space Intelligence Center (NASIC) AAM FOMs into AFEWES and GWEF. The second FY08 project will again be led by AFEWES and will integrate four DIA/MSIC RF TMAP models into AFEWES in addition to integrating two FOMs into the Navy Electronic Combat Range (ECR).

IV. History/Background

The test facilities that participated in these projects by integrating the FOM component of the TMAP models into their test architecture were all in the category of HITL test facilities. HITL facilities are unique in that they employ very high fidelity threat simulators, yet rely on software components for part of their threat system simulation. AFEWES is an example of a HITL test facility. Continuous test capability improvement at AFEWES brought at least two side-benefits. First, AFEWES was selected by Headquarters Air Force for the Modeling and Simulation Award for Acquisition for 2004. Second, it prepared AFEWES for an in-depth FOM improvement program. The following paragraphs summarize the AFEWES test capability.

AFEWES develops and operates high-fidelity RF and IR threat simulators to evaluate the effectiveness of DoD and allied EW systems in a controlled, ground-based environment. The key features of AFEWES testing include actual frequencies/wavelengths, in real-time, with dynamic engagement scenarios. The AFEWES Infrared Counter-Measures (IRCM) test facility is capable of simulating a complete IRCM test environment. This includes IR missiles in flight, aircraft in flight, and various IRCM; including flares and Directed Energy such as lamp-based or laser jamming systems. The simulation of IR missiles in flight uses hardware mounted in a six degrees-of-freedom flight motion table. Aircraft signatures and IR countermeasures are simulated with xenon arc-lamps, blackbody sources, or resistive arrays. Real-time computers control the source position and output, thereby creating the proper spatial and spectral characteristics of a missile closing in on an aircraft. Effectiveness testing of airborne laser-based countermeasures is accomplished with actual flight hardware or an appropriate surrogate laser in the optical path. This allows the directed energy beam to be controlled, modulated, and attenuated to replicate pointing and tracking system performance and platform dynamics. AFEWES provides extended source target and countermeasures capability using a resistive array-based projection system.

There are three ways RF EW systems are evaluated in the AFEWES test facility: open-loop, closed-loop and combined testing. Open-loop testing refers to stimulating a radar warning receiver (RWR) and evaluating the power-managed electronic countermeasures (ECM) response time in low, medium, and high-density threat emitter environments. This test method establishes baseline receiver sensitivity and frequency measurement capability, threat identification accuracy and prioritization, as well as response time and ECM resource allocation. Closed-loop testing looks at what effect an ECM technique may have on a high-fidelity semi-active RF SAM threat simulation. Test scenarios may include on-board self-protection and off-board self-protection by a towed decoy, as well as stand-off jamming to protect other aircraft. The goal is to assess the ECM system's ability to degrade threat guidance accuracy thus increasing the miss distance. A combined test refers to embedding a high-fidelity closed-loop threat in a realistically dense RF environment to force the EW system to function throughout the engagement from detection and track to missile launch, flyout, and endgame.

HITL facilities have a variety of different computer systems architectures. These have evolved over time as the needs and capabilities of each organization have changed. For example, in 1958, AFEWES FOMs were built using analog computer systems. By today's standards, the analog computer was not very sophisticated and special hardware such as photo function generators and servo multipliers were developed to implement the simulations. The next phase in simulation of AFEWES RF missile flyout models occurred when a 1960's era CDC 6600 hybrid computer was procured. The nonlinear aerodynamic functions were programmed on the digital computer and the guidance and flight controls were programmed on the analog computer. In order to reduce computer costs, General Dynamics initiated an Independent Research and Development (IRAD) program to purchase a Honeywell 316 digital computer to investigate the feasibility of performing real time flyout simulations on an all-digital computer. This program proved successful, and AFEWES began to purchase Honeywell 516 computers for RF flyout model simulations. As more powerful computers became available in the 1970s, AFEWES began to purchase DEC 11/60 and 11/70 computers for the RF missile simulations. These provided a great advance in the ease of programming. As personal computers (PCs) became more and more capable, an AFEWES study was initiated to determine the feasibility of performing real time flyout models on PCs. With the introduction of the Intel 486 processor, real time flyout model simulation became feasible and both RF and IR flyout models were programmed on 486 based

computers and on Pentium based computers as they became available in the late 1990s. Currently, the AFEWES simulations are built around a High Speed Interface, consisting of PCs and a SCRAMNet reflective memory system.

Through this history of FOM development, from 1958 analog computers to the present PC-based developments, AFEWES moved from developing flyout models in-house to utilizing community developed models such as Joint Modeling and Simulation System (JMASS) and now TMAP. Another common thread reaching back to early FOM development is the intellectual property of subject matter experts who continue to be instrumental in helping the FOM community to develop today's FOMs.

V. Technical Overview of Recent TMAP SAM Model Integrations at HITLs

The integration of TMAP models into HITL simulators began with a series of ground rules and assumptions. The primary ground rule was to minimize the modifications required to the core TMAP model. Since the TMAP SAM models were developed by DIA/MSIC, and they are the authoritative source on threat definition, the goal was to not disturb the model in any manner that would lead to questions concerning its validity. The core model would not change, but additional interface points would be provided to missile flyout model portions. To provide more support for this ground rule, it was determined that the appropriate intelligence center would make any interface changes needed to the model in order to ensure that the model remained valid.

A second ground rule was that the appropriate intelligence center would be presented with a single set of interface requirements from the tri-service HITL facilities. An easy solution would have been to have each HITL facility define a set of interface requirements and ask DIA/MSIC to provide a core model with a different interface for each. This would have produced a simpler set of changes for each HITL facility, but would not have produced the commonality that was a goal of this effort. By producing a single set of interface requirements and presenting these to the appropriate intelligence center, a common interface was developed to answer the needs for most HITL facilities, now and in the future.

The requirements phase began with a series of meetings at which each HITL facility identified the interface values needed for their facility. It is the nature of HITL facilities that each has a particular hardware and software mix. While one facility might implement the autopilot, aero package and gimbals software and use hardware for functions guidance and kinematics, another facility might change this mix and put different functions in software and hardware or not use particular functions at all. This different hardware/software mix requires that each facility define the interface boundaries that are expected. Since the TMAP model is a software implementation, it is necessary to provide interface points in the TMAP model for each hardware/software mix involved in the program. During the implementation phase it was sometimes necessary to revisit this hardware/software mix in order to ensure the best implementation of each system.

Having determined the interface points for each HITL facility, this information was captured in a single Interface Design Document (IDD) which was given to the appropriate intelligence center for incorporation into the core TMAP model for each FOM. The actual changes to the model consisted of a series of switches in the model to allow the insertion or extraction of data from various functions within the model and the addition of an S-Function to provide a common data point for the HITL facilities. An S-Function is a MATLAB/Simulink® function block that allows the insertion of C code into the TMAP model. By defining the inputs and outputs to the S-Function, a block was created that allowed each HITL facility to drop in the code necessary to interface with the hardware at their facility. The interface was defined to be common for all facilities, but the S-Function code varied depending on the particular implementation at each facility. Some facilities have multiple computers connected through a hardware interface, while some use only a single computer for the entire application. By defining a common interface, and providing an interface block through the S-Function, these differences could be accommodated, while still maximizing commonality between facilities.

It should be noted that this interface definition was, in fact, an iterative process. Some of the less complex TMAP models required only a single pass through the interface definition process, while the more complex models required several iterations. This was due to the nature of the hardware/software mix that was discussed above as well as an increasing level of understanding on the part of the HITL engineers about the capabilities of the TMAP models. Certain functions and scaling required preliminary integration before a complete interface could be accomplished.

Having received the IDD, DIA/MSIC implemented the interface changes into the core model to provide the HITL facilities with a modified model. Since MATLAB/Simulink®⁶ is a visual language: i.e., it is used graphically

⁶ Product name is trademarked

on a computer screen; DIA/MSIC modified the core model in a different color to aid in the understanding of what changes were made for the interface versus what was included in the core model itself. Experience has shown that the visual nature of the TMAP models definitely increases the ability of the HITL engineers to understand the workings of the model. Each HITL received the modified TMAP model, changed by DIA/MSIC with the interface needs of the combined HITL facilities.

With the receipt of the modified TMAP model from DIA/MSIC, the model was loaded in and a set of baseline runs was made to ensure that the model was functioning. The model was then converted to C code using tools provided by MathWorks. The C code is compiled and the new FOM is incorporated into the HITL in place of the existing FOM. System integration and checkout proceeded in the same fashion that would be done for the integration of any new FOM; i.e., detailed data collection plans were developed; test runs were made; data was collected, analyzed and reported.

VI. Progress: Specific TETRA FOM Projects

As referenced above, the T&E community has been making significant progress to migrate intelligence center flyout models to T&E facilities. The community learned that establishing effective partnerships can be the key to survival in the EW test arena.⁷ Due largely to teaming between the services, the TETRA office supported the startup of 4 different projects spanning FY05 – FY11 valued at nearly \$10M. The projects integrate 12 IR FOMs into 4 facilities and 6 RF FOMs into 3 facilities. The first was the FY05/06 IR FOM Project. AFEWES took the lead to obtain OSD funding for an FY05 TSWG effort to develop a common IR FOM integration methodology that not only had an intelligence center pedigree, but was also a DIA product. This FOM would then become the DoD T&E standard. AFEWES, working with DIA/MSIC, developed a comprehensive methodology to extract and modify the MATLAB/Simulink® models without changing the core threat representation. DIA/MSIC then created interfaces to the FOM portions and added the capability to integrate the models with HITL simulators. To date, two DIA/MSIC-developed IR FOMs successfully completed integration and testing at the AFEWES Missile Development Facility. These FOM initiatives are proving to be a DoD success story. A major part of the success is the teaming of Air Force, Army, and Navy test facilities to use common test tools.

A. FY05/06 IR FOM Project

The FY05/06 IR FOM Project was first successfully proposed in February 2004. TSWG presented this project to the TETRA office who, in turn, secured funding from OSD/CTEIP. Funding and authorization to start were provided in October 2004 to integrate the DIA/MSIC FOMs for 2 IR threats. The following excerpt from the project's original concept paper describes the project.⁸

1. PROJECT DESCRIPTION

- a. TEST CAPABILITY LIMITATIONS SOLVED – The need for this capability is inherent in the documented needs of all DoD infrared countermeasures (IRCM) testers since they require threat-representative SAM flyout models in hardware-in-the-loop (HITL) test facilities whenever they test IRCMs. All signs indicate future IR SAM flyout models (FOMs) will be derived by the test community from DIA/MSIC MATLAB/Simulink® products. This project will take the initial steps towards solving the shortfall of a lack of these models integrated into a HITL facility.*
- b. OBJECTIVES – The project objective is to integrate two new FOMs into several HITL facilities. The project will demonstrate the transformation of two intelligence center threat system [Infrared Surface-to-Air-Missile (IR SAM)] FOM products into operational threat system test and evaluation capabilities at Air Force, Navy, and Army HITL test facilities. This project supports DOT&E guidance by: developing capabilities that support multi-service standardization of EW test processes and methodologies, providing capability to better test*

⁷ Lessons Learned for Streamlined Operations, Increasing Capability, and Effectiveness Through Partnerships, 13 February 2006, Cheney, AIAA T&E Days 2006

⁸ Concept paper, IR SAM MATLAB/Simulink® Conversion Flyout Model (IR MATLAB FOM), 14 March 2003, Stone

Directed EO/IR Countermeasures, promoting a coherent and supportable infrastructure to support the EO/IR test domain, and by developing capability to improve end-game performance evaluation of IR countermeasure systems. This project will solve the test and evaluation shortfall/limitation of a lack of an established methodology to transform the DIA/MSIC MATLAB/Simulink® products into test-production FOMs.

- c. *DESCRIPTION – DIA/MSIC is producing MATLAB/Simulink® products which must be converted into flyout models (FOMs) which can then be economically integrated into test facilities, such as AIR FORCE/AFEWES, Army ARL, and Navy T-SPIL. All of the services' test concepts for IR SAMs include the provision of a HITL IR simulator to ascertain missile miss distance. Accurate fly-out models, which run in real-time, are essential to the simulations of the threat missiles. Real-time integration of the FOMs into HITL facilities requires precise timing interrupts and input/output capabilities necessary for hardware interface.*

This project will develop software that may be used by all HITL facilities that require real-time missile fly-out performance. Use of the TSIWG-developed methodology would allow the facilities to share a common fly-out model, which is based on current DIA/MSIC intelligence data.

- d. *TECHNICAL APPROACH - This approach, which is the initial IR implementation of the intelligence community's TMAP approach, will modify DIA/MSIC-produced MATLAB/Simulink® products in FY05 so that they will run in the C/C++ language and communicate with existing HITL architectures. During FY05, this project will develop the best methodology to transform the DIA/MSIC MATLAB/Simulink® products into test-production FOMs and will produce two beta-version real-time fly-out models in the process. The flyout models, at the discretion of the individual HITL simulators, will then be integrated into the simulators in FY06 and checked out. Checkout data will be taken to document simulator operation and will be included in a final report. Contractors will perform the work at DIA/MSIC and AFEWES.*
- e. *DELIVERABLES - The deliverables will be the software for the real-time missile fly-out models as modified for integration from MATLAB/Simulink® for the IR HITL simulators and a report that documents the transformation.*

2. TEST AND EVALUATION, TRAINING, OR WEAPON SYSTEMS SUPPORTED:

The IR simulators to be upgraded are located at the Air Force AFEWES facility in Fort Worth TX, the Army/TSMO facility in Huntsville AL, and the Navy T-SPIL facility at China Lake CA. The simulated systems are on current threat lists for the LAIRCM, DIRCM, C-130, JSF, and SAR programs. Development and operational tests to be conducted in FY06 and later include:

- a. *Jammer testing against missile receiver*
- b. *Evasive maneuver against missile receiver*
- c. *Reduced IR signature against missile receiver*
- d. *Flare testing against missile receiver*
- e. *Combined threat warning/IR countermeasures against missile receiver*

All goals have been accomplished on time and within budget⁹. The FOM project team developed a coordinated DIA/MSIC HITL FOM Methodology that can be used with future FOM programs. The team completed the integration of two DIA/MSIC models, modified by DIA/MSIC for T&E use, at Air Force, Army, and Navy HITL

⁹ Final out brief to CTEIP Committee IR SAM MATLAB/Simulink® Conversion Flyout Model Project, 8 March 2007, Stone

test facilities, and verified their performance. The team modified DIA/MSIC MATLAB/Simulink® models to run in C/C++ and communicate with existing HITL architectures at all three facilities. The successful results of the project earned and received a Letter of Validation from DIA/MSIC stating that the HITL instantiations of the FOMs are consistent with the expected TMAP performance. The team formed an ad hoc FOM Working Group that developed several conclusions/recommendations. First, tri-service cooperation saves money. Second, DIA/MSIC provided excellent support to T&E. Third, institutionalization of the FOM working group is necessary to maintain tri-service commonality. Fourth, the team maintained an intelligence-center pedigree on HITL FOMs because the methodology stressed that the core TMAP model would not be modified.

B. FY06/07 RF FOM Project

Building upon the success of the FY05/06 IR FOM Project, DOT&E/TETRA funded a separate RF FOM program in FY06¹⁰. This project applied the IR FOM migration methodology to the RF Missile Simulators at the Air Force/AFEWES, Navy/ECR, and Army TSMO. Two models were integrated at AFEWES and MoM; one was integrated at TSMO.¹¹ The applicable models will be integrated into the following test facilities:

- 1) RF SAM-B AFEWES and MoM
- 2) RF SAM-D AFEWES, MoM, and TSMO

The products of this project were RF FOMs that will be integrated into real-time hardware threat system test and evaluation capabilities at Air Force, Army, and Navy test facilities. Similar to the IR models, there are historically significant numbers of non-TMAP RF FOMs in use. However, most are not validated, are not necessarily DIA products, and performance varies from model to model. A capability shortfall therefore existed since there was no methodology established to transform the DIA/MSIC MATLAB/Simulink® RF products into test-production RF FOMs.

As with the IR FOM process, DIA/MSIC is producing RF semi-active MATLAB/Simulink® products, which must be converted into Real Time FOMs that can be economically integrated into test facilities such as Air Force/AFEWES, Army/TSMO, and Navy/MoM. All of the services' test concepts for RF SAMs include the provision of a HITL RF simulator to ascertain missile miss distance. Accurate RF fly-out models, which run in real-time, are essential to the simulations of the RF threat missiles. Real-time integration of the FOMs into HITL facilities requires precise timing interrupts and input/output capabilities necessary for hardware interface.

The current RF project is modifying two DIA/MSIC-produced MATLAB/Simulink® RF SAM TMAP models so that they will run in the C/C++ language and communicate with existing HITL architectures. The Air Force provided seed money in FY05 to jump-start this project to meet Air Force tester need dates. During FY06, this project developed methodology to transform the DIA/MSIC MATLAB/Simulink® products into test-production FOMs. It is producing simulator-ready real-time fly-out models for two RF SAMs. Integration of both models is planned to complete in early CY08.

As with the IR project, the software developed in this process may be used by all HITL facilities that require real-time missile fly-out performance. Use of the developed methodology would allow the facilities to share a common fly-out model, which is based on current DIA/MSIC intelligence data.

Development and operational tests to be conducted upon project completion include:

- 1) Reduced RF signature against missile receiver
- 2) Jammer testing against missile receiver
- 3) Evasive maneuver against missile receiver
- 4) Decoy testing against missile receiver
- 5) Combined threat warning/RF countermeasures against missile receiver

The devil is in the details. The RF FOM project is proceeding, albeit with greater difficulty than the IR project. The greater difficulty seems to be primarily due to the higher complexity of the systems simulated and therefore more strenuous integration process. It is important to note that some parts of the digital model, not surprisingly, behave differently when integrated with hardware as compared to the stand-alone digital model. Throughout the integration process, the engineering team found small items that require re-work back at DIA/MSIC. It follows that

¹⁰ TSIWG Project Management Plan, RF MATLAB/Simulink® Conversion Flyout Model Integration, Stone, 31 October 2005

¹¹ Throughout this paper the authors use the AFEWES unclassified names for the simulated threats. Each of the test facilities has their own simulator nomenclature, but the AFEWES names were used during this development project.

the team would re-accomplish the integration process and possibly find more items requiring re-work. This cycle is somewhat painful at first, but results in an excellent, verifiable product.

C. FY08/09/10/11 IR Threat Missile Model Integration Project

Confidence follows success. Based upon the success of the demonstration IR FOM project, TETRA agreed to fund the FY08/09/10/11 IR Threat Missile Model Integration project proposed by the AFEWES Program Manager.¹² This project is similar to the FY05/06 IR FOM project, with the following objectives:

- 1) Complete the integration of DIA/MSIC TMAP models into the AFEWES in Fort Worth TX for all AFEWES simulators of foreign IR SAMs.
- 2) Integrate the NASIC TMAP FOMs into AFEWES for all AFEWES simulators of foreign IR AAMs.
- 3) Integrate DIA/MISC TMAP models into the GWEF at Eglin AFB FL for all GWEF simulators of foreign IR SAMs.
- 4) Integrate NASIC TMAP FOMs into GWEF for all GWEF simulators of foreign IR AAMs.
- 5) Develop the IR SAM-M simulator at AFEWES, to include the appropriate DIA/MSIC TMAP models.

A prime difference in this project is that it adds IR AAM models and thus NASIC, the authoritative agency for air-to-air missiles. The Air Force Research Lab (AFRL) will assist NASIC. The project does not directly fund Army or Navy facilities because their major HITL facilities, T-SPIL at Michelson Labs and TSMO, already have required TMAP models in place or in work. However, coordination with the Army and Navy will occur as required. In order to ensure the T&E IRCM community has access to the best FOMs possible at multiple locations, GWEF has been included in this IR FOM project.

The integration of the TMAP real-time FOMs into the T&E facilities will use the methodology developed in the FY05 TSWG Phase I IR MATLAB/Simulink® Conversion Flyout Model project. This task will integrate a total of ten IR SAM FOMs; six will go into AFEWES; eight will go into GWEF, as indicated below:

- 1) IR SAMs
 - a) IR SAM-B GWEF (already complete or in work at AFEWES)
 - b) IR SAM-C AFEWES and GWEF
 - c) IR SAM-D AFEWES (GWEF will integrate at later time)
 - d) IR SAM-E AFEWES and GWEF
 - e) IR SAM-F GWEF (already complete or in work at AFEWES)
 - f) IR SAM-G GWEF (already complete or in work at AFEWES)
 - g) IR SAM-J AFEWES and GWEF
 - h) IR SAM-M AFEWES only
 - i) IR SAM-N GWEF (already complete or in work at AFEWES)
 - j) IR SAM-O AFEWES and GWEF
- 2) IR AAMs
 - a) IR AAM-A AFEWES and GWEF
 - b) IR AAM-B AFEWES and GWEF

DIA/MSIC will provide the TMAP models with the common T&E integration interfaces. Each facility will then adapt the common FOM for use with their specific simulator architecture. At the end of the project, test data will be collected at each test facility for each FOM for evaluation by DIA/MSIC. Upon review of qualifying data, the DIA/MSIC will issue a letter of certification stating that the results of the T&E application are consistent with the intelligence model results.

This task will also integrate a total of two IR AAM FOMs in AFEWES and in GWEF. NASIC will provide the TMAP models with the common T&E integration wrappers. Each facility will then adapt the common FOM for use with their specific simulator architecture. Lessons learned from an earlier TMAP AAM FOM integration at the Navy's T-SPIL at Michelson Labs China Lake will be considered and commonality between AFEWES, GWEF, and T-SPIL will be pursued. At the end of the project, test data will be collected at each test facility for each FOM for evaluation by NASIC. Upon review of qualifying data, the NASIC will issue a letter of certification stating that the results of the T&E application are consistent with the intelligence model results.

The IR SAM-M Integration subtask consists of the hardware design, documentation, procurement, fabrication, assembly and check-out of the hardware interfaces in the AFEWES IR Test Facility. Like the IR FOM integrations

¹² FISCAL YEAR 2008, TSWG Project Management Plan, IR Threat Missile Model Integration ", Stone, 1 October 2007

discussed above, it will use the DIA TMAP FOM. However, this task also accomplishes the integration of the hardware seeker into the AFEWES.

The IR Threat Missile Model Integration Project will include the effort at the GWEF to re-engineer the existing simulation executive to enable the use of TMAP models that have been or will be integrated into the AFEWES. This will occur in FY08, prior to integration of the first TMAP model. The design of the new executive will have to address several issues including run setup, execution control, control of lab equipment (flight table, target projectors, missile interface unit), and data logging. The existing architecture and “tool sets” have been developed and extended over the last twenty-plus years and constitute the basis of most simulations developed in the GWEF. This simulation environment is FORTRAN-based and relies heavily on global data structures (FORTRAN Common Blocks) to achieve flexibility, including rapid run setup, “batch” runs, many execution and control options, and an integrated data logging scheme that allows any simulation variable to be captured at virtually any rate. With the Simulink®-based TMAP models, a new architecture and executive software will have to be developed. Standard toolsets and data capture software will have to be modified.

Although the technical approach is similar to the FY05/06 IR SAM project, the scope is significantly larger – essentially consisting of 18 integrations of 12 models versus 6 integrations of 2 models. Therefore, this project is planned for four execution years, FY08 through FY11.

D. FY08/09/10 RF MATLAB/Simulink® Flyout Model Integration Phase-II Project

In addition to the IR simulations, significant work is needed to uplift the T&E community’s remaining simulations of RF semi-active SAMs. Leveraging the ongoing success of the FY06/07 RF FOM project, the 412th EWG’s AFEWES Program Manager proposed a 4th FOM project to TSWG. The FY08/09/10 RF MATLAB/Simulink® Flyout Model Integration Phase-II project proposal¹³ was endorsed by TSWG, TETRA, and DOT&E. The CTEIP office then agreed to provide funding. This project is similar to the FY06/07 RF FOM project, with the following objectives:¹⁴

- 1) Complete the integration of DIA/MSIC TMAP FOMs into AFEWES in Fort Worth TX for all AFEWES simulators of foreign semi-active RF SAMs
- 2) Complete the integration of DIA/MSIC TMAP FOMs into Navy Electronic Combat Range (ECR) facilities at China Lake CA for all ECR simulators of foreign semi-active RF SAMs

Again, the product of this project will be FOMs that can be integrated into real-time hardware threat system test and evaluation capabilities at Air Force and Navy test facilities. Models to be integrated are the AFEWES RF SAM-A, RF SAM-C, RF SAM-E, and RF SAM-G. These models will be integrated as follows.

- 1) RF SAM-A AFEWES only
- 2) RF SAM-C AFEWES and ECR
- 3) RF SAM-E AFEWES only
- 4) RF SAM-G AFEWES and ECR

A slightly different methodology will be considered for the RF SAM-C system. In this project, the TMAP models may be segmented to allow the test facilities to use only the subsystems necessary so that the test facility will not need to run the portions of the model that are not of concern. This methodology change is basically putting wrappers around subsystems of only the FOM components instead of developing one interface combined with the entire SAM TMAP model, as was done previously. Once the TMAP models are disassembled and the appropriate wrappers developed, the HITL ready TMAP FOM will be integrated into the AFEWES and ECR test facilities. This modified approach will be investigated to see if it will streamline the test facility integration process.

VII. Ongoing FOM Support Challenges

For the future, this success story should be applied to the rest of the T&E community. TETRA recently formed the Threat Test Capabilities Working Group (TTCWG) to address a wide variety of potential T&E issues. The TTCWG has paid significant attention to the issue of FOMs: specifically the goals of developing common FOMs, using intelligence center products, and establishing a sustainment program for T&E FOMs. In fact, it formed two

¹³ RF MATLAB/Simulink® Flyout Model Integration Phase-II proposal briefing, Stone, 16 January 2007

¹⁴ Project Management Plan, RF MATLAB/Simulink® Flyout Model Integration Phase-II”, Bryson, 17 October 2007

applicable sub-groups. One of the goals of the first group is to locate and promote funding for a repository for the T&E standard FOMs. It strives to define the requirements to maintain (sustain) the accomplishments in the FOM world. The second subgroup is a FOM requirements subgroup. The specific goals and charter of this FOM subgroup are under development, but it should provide an appropriate forum for FOM issues. Eventually, someone will need to inventory T&E needs of other HITLs, facilities using all-digital FOMs, open air ranges, etc.

The group will need to reach out to the T&E community to convince them to adopt common FOMs. Only in this way can commonality be maintained. For example, it was noticed that a sister service's facility was building a new simulator, which included a TMAP FOM. Unfortunately, the model integration was not coordinated with other T&E facilities. Upon making contact, the facility readily agreed to participate to maintain commonality. Realizing that many facility developers are over-tasked, it will take an overt effort to aid and partner with others.

An additional challenge to be faced is the out-year revision of a FOM once it has been installed in the T&E facility. This need to make updates is attributable to many factors: intelligence baseline changes, errors in the original are found, to make the model more applicable to broader community, etc. The HITL will coordinate the change with the intelligence community to determine if the change is significant enough to require re-integration and re-verification. Notionally, the labor requirement and therefore the cost should be relatively low. However, the T&E modifications to the FOM and the integration effort still must be performed.

The T&E community will need to strive to continue to meet DOT&E vision to “. . . provide high fidelity test tools to the warfighter; and this can only be accomplished when the AF, Army, and Navy cooperate to develop test capabilities that have an intel pedigree and are consistent when testers go from one test facility to another. . .”

VIII. Lessons Learned

Through this process of developing a common interface for the Air Force, Navy and Army facilities, several lessons have been learned and are being applied to subsequent FOM projects. These lessons include technical issues and issues involving the interactions of different organizations and services.

- 1) TMAP models were created by the intelligence community to address their needs. Often the level of fidelity within the model varies from component to component based on the needs of the developers of the original models (the intelligence community). When these models are moved into the T&E community, the fidelity of certain components may not be of a sufficient level to support certain sophisticated operations, such as those encountered in a HITL facility. At this point it is necessary to revisit the model itself and increase the fidelity of the components important to the HITL community. The advantage of doing this is that by having more subject matter experts examine the model, the fidelity of the model is improved and enhanced. As more facilities take a hard look at the FOM, the likelihood that the model will contain errors decreases. This requires that the intelligence community be open to changes that are needed by the HITL community, and the experience of this project is that the intelligence community welcomes the T&E community suggestions. The support of the applicable intelligence agencies is paramount for projects such as these. The assistance and cooperation of NASIC and DIA/MSIC have been outstanding.
- 2) The benefit(s) to the T&E community achieved by the implementation of joint FOMs is greater than the limited inconveniences incurred during the development. The managers of these FOM upgrade projects recognized from the start that a large standardization effort required initial small sacrifices by individual test facilities. In order to capture all applicable facilities' requirements, the participants were required to spend additional time on the developmental efforts than they would have if they had been working independently. Additionally, the ideal technical integration solution for a particular facility was not always the ideal solution for another facility. However, achievement of standardized, validated models across the services' HITL facilities is well worth the difficulties.
- 3) Projects such as these bring together many people from several services, agencies, and organizations. It follows that they do not report directly to the project manager. The manager then, by definition, has no direct authority over the team members. Therefore, the manager is highly dependent on team work and cooperation of the applicable members. The manager must have the skills to communicate clear goals, roles and responsibilities, etc in order to achieve success.
- 4) Coordination between geographically separated organizations proved to be a problem. For example, the coordination of classified Interface Design Documentation took twice as long as originally planned.

SIPRNET was not reliable, and when it did work properly, only the government point of contact was authorized to get the document off the SIPRNET to ship it to the contractor. The mitigation was to ensure that classified details are not included in the documents until absolutely necessary. Another delay was experienced when the coordination document was a formal delivery from the contractor to the government. Each time a revision was made, a time-consuming coordination process was required. These delays are being mitigated by keeping the coordination copies of documents in draft until the final copy is published for delivery to the government

- 5) The probability of success of tri-service projects such as these is significantly increased when they are supported by OSD agencies. TETRA recognized a tri-service T&E need that could be remedied by supporting the threat intelligence agencies' TMAP efforts. The support of DOT&E/TETRA and TRMC/CTEIP has been invaluable.

IX. Conclusion

The T&E and intelligence communities have long recognized the need to emplace valid flyout models of threat IR and RF missiles into the facilities that test and evaluate aircraft defensive systems. When the sheer number of the threats is considered, this task is indeed daunting. Assisted by OSD, the Air Force's AFEWES personnel led quad-agency teams to address the need. Building on lessons learned from legacy flyout models and decades of experience, the IR team began by developing the methodology to integrate two of DIA's newest IR flyout models into three HITL facilities: one each from the Army, Navy, and Air Force. An RF team, again led by AFEWES personnel, built upon that experience to begin integrating two of DIA's newest RF flyout models into three HITL facilities: again, one from each of the services. The OSD multi-year endeavor is continuing with a goal of completing the integration of all applicable IR and RF semi-active flyout models into AFEWES, T-SPIL, GWEF, ECR, and TSMO. The key to continuing success is to bring stakeholders together, in an atmosphere of trust, to conduct formal and informal discussions, as well as to create consensus on flyout model needs in an environment where priorities, objectives, and roles of each member are considered and valued.

Appendix I

Acronyms

AAM	Air-to-Air Missile
AFEWES	Air Force Electronic Warfare Evaluation Simulator
AFRL	Air Force Research Laboratory
ARL	Army Research Laboratory
COTS	Commercial-off-the-Shelf
CTEIP	Central Test and Evaluation Investment Program
DIA	Defense Intelligence Agency
DIRCM	Directed Infrared Countermeasures
DoD	Department of Defense
DOT&E	Director, Operational Test and Evaluation
ECM	Electronic Countermeasures
ECR	Electronic Combat Range
EW	Electronic Warfare
EWG	Electronic Warfare Group
FOM	Flyout Model
GWEF	Guided Weapons Evaluation Facility
HITL	Hardware in the Loop
IDD	Interface Design Document
IR	Infrared
IRAD	Independent Research and Development
IRCM	Infrared Countermeasures
JSF	Joint Strike Fighter
JMASS	Joint Modeling and Simulation System
LAIRCM	Large Aircraft Infrared Countermeasures
MoM	Missile on the Mountain
MSIC	Missile and Space Intelligence Center
NASIC	National Air and Space Intelligence Center
OAR	Open Air Range
OSD	Office of the Secretary Defense
PC	Personal Computer
RF	Radio Frequency
RWR	Radar Warning Receiver
SAM	Surface-to-Air Missile
SAR	Special Access Required
T&E	Test and Evaluation
TETRA	Test and Evaluation Threat Resource Activity
TMAP	Threat Modeling and Analysis Program
TRMC	Test Resource Management Center
TSIWG	Threat Systems Investment Working Group
TSMO	Threat Systems Management Office
T-SPIL	Threat Signal Processor-in-the-Loop
TSWG	Threat Systems Working Group
TTCWG	Test Threat Capability Working Group